

or temperature of the molecule. He considers our earlier results to range very much as is to be expected, the interchange of energy with the molecules of the platinum wall being less perfect for the lighter gas molecules than for heavier ones, and also for polyatomic than for monatomic, for the reason that intramolecular energy is less disposed to equalisation by impacts than energy of progressive motion.

It is clear that further experimental work must be done in the manner suggested before the necessary data are available. The experiment on the conduction of hydrogen with palladium and platinum wires tells against the idea of imperfect interchange of energy, but it is by no means conclusive. Moreover, Prof. Larmor remarks that the recent experiments of Millikan on electrified water drops in an electric field, when interpreted by the formula of E. Cunningham,* make β very small, so that, for air on water at any rate, little correction of that kind arises.

*An Electrostatic Voltmeter for Photographic Recording of
Atmospheric Potential.*

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The difficulties attending continuous registration of electrical potential gradient of the atmosphere are very great; but it is not my intention in this paper to discuss these. My object is to call attention to the measuring part of an electrograph, and more especially to experiments made with an instrument that promises to be of considerable service in work of this kind. A recording voltmeter ought to have a uniform scale value over the range for which it is intended to be used, it must possess a high degree of insulation, and it ought to be capable of acting efficiently for long periods without having to be taken to pieces for cleaning. The general excellence of the Dolezalek electrometer and its high degree of mechanical symmetry suggested to me its use as a recorder, although I do not know that it has been tried before.

The instrument was designed to measure very small differences of potential

* 'Roy. Soc. Proc.,' 1910, A, vol. 83, p. 109.

between the quadrants with a potential of, say, 100 volts on the needle. The first thing to ascertain was whether, with a fixed difference due to a single Weston cell, the sensitiveness could be reduced so that the movement of the needle would record, on a suitable scale, the potential applied to it. A trial suspension made of phosphor bronze proved successful, and a scale value of about 200 volts per centimetre was obtained on the photographic paper, which is carried on a drum 1 metre from the mirror attached to the needle. Up to 500 or 600 volts the behaviour was excellent, but for higher potentials the needle began to tilt, and if a sudden change was made the needle generally discharged to the quadrants. Experience showed that it would have frequently to carry over 1000 volts. The needle was therefore loaded by prolonging the vertical axis to about 3 cms. beneath the needle, and adding at the end a small brass nut of about $1\frac{1}{2}$ gm. It now carries 1100 volts with perfect safety and stability.

The loading reduced the sensitiveness, and I now use three Weston cells and obtain a scale value of about 115 volts per centimetre on the paper. As far as I can test with a high potential Wulf electrometer, the scale value is constant to within 2 or 3 per cent. over the range of the sheet, which is about 900 volts + or -. It requires a little care and patience to adjust the instrument to symmetry over this large range of 1800 volts.

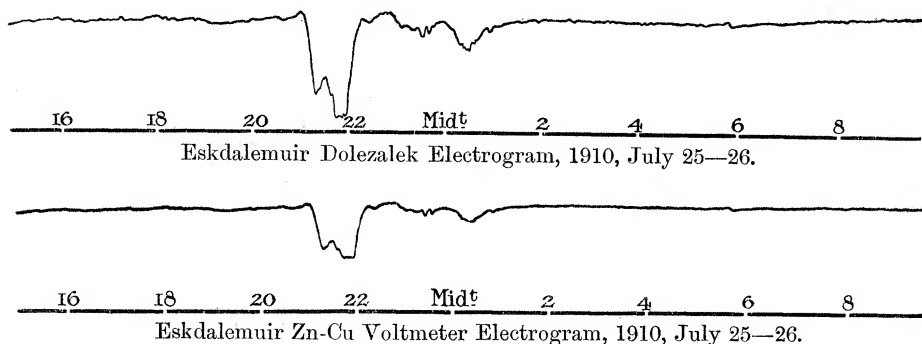
The present scale value is suitable for ordinary days, but in stormy weather it is too large. We therefore require a second voltmeter working at a lower sensitiveness in order to get a complete record. From what has been said, it is clear that a Dolezalek with one Weston cell would serve admirably. It may be mentioned that although the instrument is not dead-beat at this sensitiveness, the needle comes to rest long before the collecting water-jet responds to change of potential, but discussion of this point is reserved for another occasion.

Meanwhile experiments in another direction have been carried on. Some ten years ago Mr. W. G. Pye made for me an experimental voltmeter, in which I proposed to rely on the contact difference of potential between zinc and copper to give a couple on a suspended electrometer needle. Two circular plates were made up of alternate 90° sectors of zinc and copper, soldered together at the junctions, and the two plates were set parallel by means of a circular copper ring, thus completing the "box quadrant" arrangement.

I was satisfied some years ago that the instrument could be adjusted to give quite reliable readings for a steady potential on the needle. When the question of having a second recorder for high potentials arose, it occurred to me to ascertain if the zinc-copper voltmeter would do. The old plates

were accordingly looked out, and, although they had been damaged and repaired some years ago, an instrument was made up in the observatory workshop, closely resembling the Dolezalek in general features, although equal mechanical accuracy was impossible in the circumstances.

When connected to the Dolezalek and collecting system, the photographic records from the two instruments were perfectly similar. Fig. 1 is a reproduction of a specimen record.



It proved fairly easy to adjust the new instrument to uniform scale value (about 290 volts per centimetre) over a range of 400 or 500 volts + or -; but for greater potentials I found considerable difficulty. This arose simply from the lack of perfect mechanical symmetry in the instrument, but with patience I finally succeeded in getting practical uniformity up to 1100 volts + or -.

I think these results, obtained with a "home-made" instrument, warrant the making of a new one, which shall equal in mechanical precision the Dolezalek electrometer, and so admit of easier adjustment. At present the needle is not sufficiently damped for very rapid changes, but this can be overcome by using a Dolezalek needle or by electromagnetic damping.

The instrument possesses an obvious advantage for recording work, as insulation of the quadrants is unnecessary. The only part requiring good insulation is the head for carrying the needle. This may be done with amber, but we avoided the expense and got quite as good a result by moulding a sulphur bush.

The question of a cheap and efficient insulator is strictly beyond the scope of this paper; but as we have obtained most satisfactory results by using sulphur, I have been advised to refer to the matter.

It is practically impossible to work sulphur in the ordinary mechanical way, and resort must be had to moulding. For this purpose a carefully cleaned glass tube or test-tube of the required diameter is used. Ordinary

roll sulphur is then melted in a clean porcelain dish, and it is essential that the temperature should be just sufficient to melt the sulphur and no more. The slightest darkening of the liquid is fatal to a good result. The molten sulphur is run into the glass tube and allowed to set for 24 hours. It may then be taken out, and usually the test-tube has to be sacrificed in the process. Initially the rod insulates magnificently, but in the course of a few days it gets defective. If, however, the glossy surface is then removed by light rubbing with fine sand-paper, the insulating power is recovered and maintained. I cannot yet say how long this will last, but I have some pieces in use that have not been touched for over six months, and they insulate now as well as they did originally and quite as well as amber. I have made special tests in very damp weather without finding any failure of the sulphur. If the support has to stand any strain it may be fitted into a brass socket with a piece of thin paper. Five such supports, 1-inch diameter, carry our copper tank, which is 3 feet in diameter and 6 inches deep and filled with water. An idea of the insulation may be obtained from the fact that when electrified the tank falls to $1/e$ of its original potential in from 50 to 60 minutes normally.

I have found that sulphur moulded directly into brass or copper tube gradually deteriorates, and on breaking the sulphur it is found to contain dark streaks of what I presume is copper sulphide. If, however, the brass is first lined with thin paper the sulphur maintains its insulating power for months without any sign of deteriorating.

It is important not to touch the sulphur with fingers at all greasy. If occasion arises to remove a spider's thread, it is best to do so with a piece of fine sand-paper or even a piece of fine tissue paper.

Mr. Black, the observatory mechanic, has greatly assisted me in ascertaining what precautions are necessary to make sulphur a serviceable insulator in laboratory work.

[*Note added December 8.*—Zinc-copper couples have been used before by Lord Kelvin and by Prof. C. V. Boys.* Sulphur insulation, with the remarkable efficiency of which this paper is concerned, has also been advocated by Mr. C. T. R. Wilson, by Dr. Threlfall, and by Prof. Le Cadet.†]

* 'Electrician,' 1896.

† 'Annales de l'Université de Lyon,' 1898, vol. 35, p. 32.